Neuroscience of Consciousness, 2016, 1–9

doi: 10.1093/nc/niw013

Rapid Communication

Subliminal messages exert long-term effects on decision-making

Simon Ruch*, Marc Alain Züst, and Katharina Henke

Department of Psychology, University of Bern, Switzerland and Center for Cognition, Learning and Memory, University of Bern, Switzerland

*Correspondence address. Department of Psychology, University of Bern, Fabrikstrasse 8, 3012 Bern, Switzerland. Tel: +41 (0)31 631 40 11; E-mail: simon.ruch@psy.unibe.ch

Abstract

Subliminal manipulation is often considered harmless because its effects typically decay within a second. So far, subliminal long-term effects on behavior were only observed in studies which repeatedly presented highly familiar information such as single words. These studies suggest that subliminal messages are only slowly stored and might not be stored at all if they provide novel, unfamiliar information. We speculated that subliminal messages might affect delayed decision-making especially if messages contain several pieces of novel information that must be relationally bound in long-term memory. Relational binding engages the hippocampal memory system, which can rapidly encode and durably store novel relations. Here, we hypothesized that subliminally presented stimulus pairs would be relationally processed influencing the direction of delayed conscious decisions. In experiment 1, subliminal face–occupation pairs affected conscious decisions about the income of these individuals almost half an hour later. In experiment 2, subliminal presentation of vocabulary of a foreign language enabled participants to later decide whether these foreign words are presented with correct or incorrect translations. Subliminal influence did not significantly decay if probed after 25 versus 15 min. This is unprecedented evidence of the longevity and impact of subliminal messages on conscious, rational decision-making.

Key words: subliminal; decision-making; unconscious processing; long-term memory; hippocampus; information integration

Introduction

Subliminal messages exert diverse influences on our thoughts and our behavior (van Gaal *et al.*, 2012; Hassin, 2013). Subliminal stimuli can facilitate conscious processing of related information (Van den Bussche *et al.*, 2009), change our current mood (Monahan *et al.*, 2000), boost our motivation (Aarts *et al.*, 2008), and can even alter our political attitudes and voting intentions (Hassin *et al.*, 2007; Weinberger and Westen, 2008). With such a broad impact, subliminally planted information might have the potential to alter our decisions in everyday situations such as voting.

In order to influence decision-making in real-life situations, subliminal messages must be stored for long-term after only a few exposures, e.g. after a single confrontation with a subliminal TV advert. Furthermore, messages must be stored even if they contain complex relational information that requires semantic integration, such as "politician X will lower the taxes." For subliminal manipulation to be effective, humans thus have to be able to semantically integrate and rapidly store unconscious pieces of novel information into long-lasting associative memories that can be retrieved if relevant to the context of a later decision.

The processes which allow novel information to shape subsequent decisions are generally thought to depend on consciousness – be it the integration of novel information into abstract mental representations (e.g. Tononi, 2004), rapid encoding of these representations into long-term memory (e.g. Shanks, 2010), or the use of these representations to make informed decisions (e.g. Newell and Shanks, 2014). However,

Received: 9 December 2015; **Revised:** 1 July 2016. **Accepted:** 22 July 2016

growing evidence indicates that the human unconscious can perform various high-level cognitive functions (van Gaal *et al.*, 2012; Hassin, 2013) that might allow decision processes to benefit from subliminal messages.

Several studies reported that subliminally planted information can be semantically integrated outside conscious awareness (for a detailed review, see Mudrik *et al.*, 2014). Indeed, humans can detect incompatible object-background configurations in subliminal scenes (Mudrik and Koch, 2013), solve subliminally presented arithmetic problems (García-Orza *et al.*, 2009; Van Opstal et al., 2011; Sklar *et al.*, 2012; Karpinski *et al.*, 2016), and draw inferences from subliminal picture sequences and word pairs (Kawakami and Yoshida, 2015 and Reber and Henke, 2012, respectively).

Subliminal stimulation was further found to nonconsciously shape decision-making – at least if masked stimuli consisted of single familiar items that required little integration. For example, priming studies reported that subliminal primes not only facilitate correct responses to related targets in a classification task, but also bias responses in "free choice" tasks in which participants can freely decide between response alternatives (Schlaghecken and Eimer, 2004; Klapp and Haas, 2005; Kiesel et al., 2006; Parkinson and Haggard, 2014; Ocampo, 2015). Similarly, studies on subliminal persuasion suggested that repeated subliminal exposure to brand names (e.g. "Lipton Ice Tea") or goal-relevant words (e.g. "thirst" in thirsty participants) can bias participants' product choices (Karremans *et al.*, 2006; Bermeitinger *et al.*, 2009; Verwijmeren *et al.*, 2011, 2013) or reinforce a certain behavior (e.g. to drink, see Strahan *et al.*, 2002). Thus, there is ample evidence that subliminal messages can be integrated unconsciously and can influence decisions and choices.

Whether subliminally presented information is stored in long-term memory to guide delayed decisions is vastly unknown. So far, studies on information integration and decision-making only assessed immediate influences of subliminal stimulation. Priming studies which assessed the longevity of subliminal influences usually reported that behavioral effects of masked primes decay within 1 s (e.g. Forster *et al.*, 1990; Ferrand, 1996; Greenwald *et al.*, 1996). This suggests that subliminal information is not stored and thus cannot affect delayed decisions. Yet, some studies reported that longer lasting subliminal influences on behavior are possible under certain conditions. In many of these studies, the same subliminal messages were presented multiple times (Lowery et al., 2007; Capa *et al.*, 2011; Levy *et al.*, 2014; Farooqui and Manly, 2015). Furthermore, participants were often informed about the presence of subliminal stimuli and were provided conscious feedback or rewards after each subliminal message (Aarts *et al.*, 2008; Capa *et al.*, 2011; Farooqui and Manly, 2015) or were asked to consciously detect or classify each subliminal event (Gaillard et al., 2007; Chen *et al.*, 2009; Chong *et al.*, 2014). These studies thus suggest that subliminal messages are only slowly stored and are only retained if subjects have the explicit intention to process the hidden events. Importantly, most studies used familiar information such as single words as subliminal stimuli to prime subsequent conscious processing of this information (Gaillard et al., 2007; Chen *et al.*, 2009; Chong *et al.*, 2014) or to prime a specific goal (e.g. to perform well on a test), intention, or stereotype (Lowery et al., 2007; Capa *et al.*, 2011; Levy *et al.*, 2014). This suggests that subliminal long-term effects are achieved only if familiar information is presented but not if novel relational information has to be learned.

We asked if humans can rapidly integrate and store novel relational information (e.g. "person X is a manager", see Fig. 1a) from subliminal messages for later use in a decision-making situation (e.g. "guess the income of X"). We speculate that subliminal messages should be stored especially if they consist of multiple items that require relational processing. Relational binding calls upon the hippocampal memory system, which can rapidly store novel relations for long term (Henke *et al.*, 1997; Holdstock *et al.*, 2002; Harand *et al.*, 2012). Traditional views hold that hippocampus is only involved in the encoding and retrieval of consciously perceived information (Moscovitch, 1995; Squire and Zola, 1996; Tulving, 2002), and that associative learning outside conscious awareness is unlikely (Shanks, 2010). However, growing evidence suggests that hippocampus operates independently of consciousness and that nonconscious relational learning is humanly feasible (for reviews, see e.g. Reder *et al.*, 2009; Henke, 2010; Dew and Cabeza, 2011; Hannula and Greene, 2012; Olsen *et al.*, 2012). Indeed, hippocampus was found to mediate implicit learning (Chun and Phelps, 1999; Greene *et al.*, 2006; Negash *et al.*, 2015) and retrieval (Greene *et al.*, 2007; Hannula and Ranganath, 2009; Addante, 2015; Reber *et al.*, 2016) of relational information between visible stimuli. Most importantly, hippocampus was also found to be involved in the encoding and retrieval of subliminally presented stimulus pairs (Henke *et al.*, 2003; Reber *et al.*, 2012; Duss *et al.*, 2014; Züst *et al.*, 2015).

We ran two experiments to test whether subliminal stimulus pairs would affect delayed decision-making (Figure 1a). In experiment 1, we tested whether subliminal presentations of face–occupation pairs would guide later conscious decisions about the income of the same faces. We assessed the longevity of subliminal influence by measuring its decay across delays of 15–25 min. In experiment 2, we assessed if new vocabulary of a foreign language is acquired subliminally affecting later lexical-semantic decisions on the same foreign words. Both experiments were composed of an encoding phase, an encoding-test interval that was filled with rest, and a test phase (Fig. 1a). The decision task given in the test phase constituted an indirect (implicit) memory test. Importantly, participants were kept naïve regarding subliminal stimulation until the end of the experiment. This allowed us to assess subliminal influences in the absence of any explicit intention to process the hidden messages.

Method

General procedure

Unless indicated otherwise, experimental procedures were identical for both experiments. We used a well-established paradigm to render stimuli invisible (Duss *et al.*, 2011). Each stimulus was presented 12 times for 17 ms during one unconscious encoding episode of 6 s duration (see Supplementary Fig. 1). Stimuli were preceded and followed by visual noise masks (sandwich masking). In experiment 1, 40 face–word pairs were encoded in 40 unconscious encoding episodes. In experiment 2, each unconscious encoding episode contained a pseudoword–word pair that was presented twice in nonadjacent repetitions, yielding a total of 48 encoding episodes for 24 pseudoword–word pairs. Stimuli and masks were embedded in an attention task which allowed us to direct participants' focal attention to the screen without disclosing the presence of subliminal messages (see Supplementary Fig. 1). The task required participants to respond to target screens that appeared at random times once in every encoding episode (see Supplementary Fig. 1). Mean hit rate to targets was >85% in both experiments. Following the attention task, participants rested for 15, 20, or 25 min (depending on experiment and condition) before performing the decision tasks. The attention task and the decision

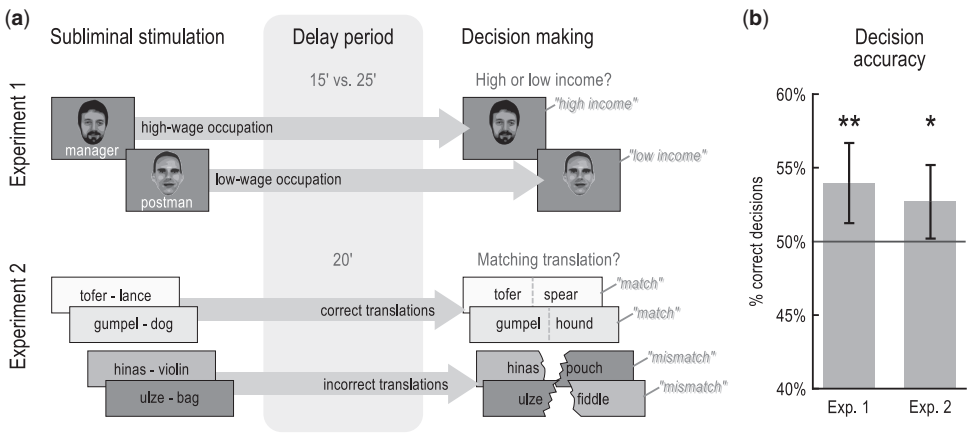

Figure 1. (a) Design of experiments 1 and 2. Subliminal presentation of face–occupation pairs (Experiment 1) or pairs consisting of pseudowords and their translations (Experiment 2) altered participants' decisions when later asked to rate the income of faces or to identify correct (matching) translations of pseudowords. (b) Results. Two-tailed *t*-tests indicated that decision accuracy was significantly above the 50% chance level (mean accuracy with 95% confidence interval). $^{*}P < 0.05$, $^{**}P < 0.01$.

task were briefly practiced at the beginning of the experiment using a few stimuli that were not used later on.

Following the main experiments, a structured interview was performed to assess subjective awareness for subliminal information. Using funneled questions, we first asked participants whether they had seen any unexpected stimuli during the attention task or had suspected the presence of any hidden information, and then asked more specifically whether they had seen hidden faces or words. We then informed participants of the subliminal stimulation and administered forced-choice tests to assess awareness of subliminal stimuli objectively. Masking paradigm and attention task in these awareness tests were the same as in the main experiments. However, awareness was tested trial-by-trial: following each encoding episode of a new stimulus pair, the attention task was interrupted and participants were asked to provide information about the subliminal stimuli. We expected participants to perform at chance level in these tests if masking rendered stimuli truly subliminal.

Experiments were approved by the local ethics committee. Written semi-informed consent was obtained from all participants before experimentation. The information about subliminal stimulation was provided following the experiment.

Participants

We recruited participants with normal or corrected-to-normal visual acuity. In experiment 1, two participants were excluded *post hoc* due to errors in data logging. Of the remaining 46 participants (19 men and 27 women, mean age = 36.0), 23 were tested with a 15 min delay between subliminal encoding and decision-making, and 23 with a 25 min delay. In experiment 2, two participants were excluded *post hoc* because they had failed to report their decisions within the response time window. The remaining sample consisted of 23 women and 11 men (mean age = 22.8).

Experiment 1

During the encoding phase, we presented 10 faces combined with written high-wage occupations and 10 faces with low-wage occupations (Fig. 1a). Twenty additional faces were paired with consonant strings and presented subliminally in a control condition (not reported). Each stimulus pair was presented in just one subliminal encoding episode, which comprised 12 stimulus repetitions within 6 s. The encoding-test interval spanned 15 or 25 min. In the test phase, the former subliminal faces were re-presented for 5 s for conscious inspection with the instruction to decide whether an individual would earn a high or low income.

Objective awareness tests

We administered two forced-choice tests to assess awareness of subliminal faces and occupations objectively. In each test, we presented 40 novel face–occupation pairs subliminally using the same attention task as in the main experiment. Immediately following the encoding of a novel pair in a subliminal encoding episode, the attention task was interrupted and participants were interrogated regarding the just presented face or occupation. In the face-awareness test, the just subliminally presented face and a novel face were presented side by side for conscious inspection. Participants were asked to select the face that they thought was just flashed subliminally. In the occupation-awareness test, the text "Income?" was presented which signaled participants to name the income ("high" vs. "low") that they thought would the just subliminally flashed occupation yield. After giving their response, the attention task was continued and a new face–occupation pair was presented subliminally. Participants took either 40 face-awareness trials followed by 40 occupation awareness trials or vice versa.

Material

We used 160 grayscale images of male faces that were given average income ratings in a pilot study. Images were equalized regarding luminance and contrast and were assigned to 16 lists of 10 faces each. Lists were comparable with respect to income, age, facial hair, and emotional facial expression. Lists were counterbalanced over experimental conditions such that each face was presented an equal number of times with a high- and a low-wage occupation and with a consonant string. All faces were also rotated into the two awareness tests. Stimuli were presented an equal number of times in the main experiment, and the awareness tests of faces and occupations. Hence, results in the experiment and the awareness test derived from the same stimulus material (presented to different participants).

We used 10 typical high- and 10 low-wage occupation words that were similar regarding mean logarithmic word frequency

(Leipzig Corpora Collection, http://corpora.uni-leipzig.de/) and character count.

Faces were displayed at the center of the screen in front of a dark gray background. Words were presented below the faces in light gray in a *sans-serif* font. Stimuli were delivered at a visual angle of 15° using a Digital Light Processing (DLP) projector with a 60 Hz refresh rate.

Experiment 2

Participants encoded 24 combinations of written pseudowords (fictitious foreign language) and German words (fictitious translations). We presented these pseudoword–word combinations subliminally for unconscious semantic relational encoding using the same paradigm as in experiment 1. There were two nonadjacent subliminal encoding episodes (each comprising 12 stimulus repetitions within 6 s) per word pair within a randomized sequence of subliminal encoding episodes. The encoding-test interval spanned 20 min. At test, we re-presented the same foreign words for 5 s for conscious inspection. Each foreign word was shown besides a German word that was a synonym to the subliminal German translation of either this or another foreign word. Synonyms were used to test for semantic rather than perceptual relational retrieval. Half of foreign words presented at test were recombined to break the encoded semantic relation (incorrect translations) and half were combined to keep the semantic relation from encoding to test (correct translation). Participants were instructed to decide whether or not a presented foreign word and the German translation word fit together (match/mismatch decision).

Objective awareness test

We administered one forced-choice test to assess awareness of subliminal words objectively. Participants encoded 24 (novel) pseudoword–German word pairs. Following each subliminal encoding episode, a probe word was displayed for conscious inspection for participants to decide whether or not the probe was a synonym to the just presented subliminal German word. In half the trials, the probe was a valid synonym to the subliminally presented German word, in the other half the probe was an unrelated foil. Hence, we assessed the semantic processing of subliminal words, as in the main experiment.

Material

We created 48 word triplets consisting of a pseudoword, its German translation used for subliminal encoding, and a synonym to the German translation used for the decision task (see Fig. 1). German synonym pairs were gathered from Open Thesaurus (http://www.openthesaurus.de/). Two-syllabic pronounceable pseudowords were created using German and Dutch syllables provided by the Celex database (http://celex.mpi.nl/). The 48 encoding stimuli were assigned to four lists of 12 items each with equal distributions of word lengths, pronounceability, concreteness, animatedness, and logarithmic frequency of appearance (drawn from Leipzig Corpora Collection, http://corpora.uni-leipzig.de/). Assignment of German translations to pseudowords was randomized anew for each list and each participant to reduce potential bias resulting from particular combinations. Two lists were used for the main experiment and the other two lists for the awareness test; this assignment was counterbalanced over participants. Twelve further German words were used as foils in the awareness test. Pseudowords were displayed in the left and German words in the right visual field of participants. Words were presented for subliminal encoding using the same masking paradigm and psychophysical conditions as applied in experiment 1.

Results

Experiment 1

In experiment 1, we tested whether subliminal presentations of face–occupation pairs would influence later classification of the same faces. We hypothesized that participants would rate individuals who had earlier been flashed with a high-wage or low-wage occupation as high-income or low-income earners, respectively. A two-tailed *t*-test on the mean decision accuracy confirmed this hypothesis. Mean decision accuracy was 53.97% (95% CI [51.25, 56.96]), which exceeded the chance level of 50% ($t(45) = 2.94$, $P = 0.005$; $r = 0.40$) (Fig. 1b). Mean decision accuracy was not significantly smaller after 25 compared to 15 min (53.04% vs. 54.90%; two-tailed $t(44) = 0.68$, $P = 0.50$; $r = 0.10$), which indicates that the effect of subliminal encoding persisted through both retention intervals at equal strength. Hence, new semantic associations were stored for long term affecting the direction of decision-making almost half an hour later.

An interview that was administered after the main experiment to assess subjective awareness of the masked stimuli suggested that none of the participants had seen the subliminal faces or words during encoding. Two objective awareness tests further indicated that masked stimuli could not be consciously perceived. Participants performed at chance level of 50% if asked which one of two faces had just been presented subliminally (mean recognition accuracy = 48.81%, 95% CI [46.36, 51.27], missing data of one participant due to data loss) or if a high-or low-wage occupation had been presented (mean recognition accuracy = 49.06%, 95% CI [46.90, 51.23]). The *t*-tests against chance level were not significant (awareness for faces: $t(43) = -0.98$, $P = 0.34$, $r = 0.15$; awareness for occupations: $t(44) = -0.90$, $P = 0.37$, $r = 0.13$), suggesting that participants were consciously unaware of the subliminal stimuli. However, the nonsignificant tests do not reveal whether participants were truly unaware (i.e. whether H0 can be accepted), or whether our tests were not sensitive enough to detect awareness. We, therefore, calculated Bayes factors for the two *t*-tests following the recommendations provided in Dienes (2008, 2014). Bayes factors (BF) indicate the relative strength of two hypotheses H1 and H0 with a BF(H1/H0) = 1 suggesting that the data are inconclusive and favor neither hypothesis, and BFs > 3 or < 1/3 suggesting substantial evidence for H1 or H0, respectively. Assuming that awareness of subliminal stimuli should yield recognition accuracy that is comparable to performance in the decision task (3.97% above chance level), we chose a half-normal prior distribution with a mode of 0 and a standard deviation of 3.97% to calculate BF (Dienes, 2014). The resulting BF for the face-awareness test (mean accuracy = 1.19% below chance level, SE = 1.21%) and the occupation-awareness test (mean accuracy = 0.94% below chance, SE = 1.04%) were 0.16 and 0.14, respectively. Both factors were below 1/3, indicating substantial evidence for the null hypothesis, i.e. that participants were not aware of the masked stimuli. We further performed a multiple regression analysis to assess whether potential awareness of faces or occupations predicted decision accuracy in the main experiment, and to estimate whether accuracy remained above chance level if the theoretical awareness in both tests is 0 (i.e., whether the intercept is significant). This method was brought forward by Greenwald *et al.* (1995). Although subject to criticism (e.g. Miller, 2000), this method is used widely to assess whether

subliminal influences on behavior are independent of stimulus awareness. Neither potential awareness of faces ($\beta = 0.16$, $t(41) = 0.88$, $P = 0.383$) nor potential awareness of occupations ($\beta = 0.24$, $t(41) = 1.2$, $P = 0.23$) predicted decision accuracy in the main experiment. Decision accuracy in the main experiment remained above chance level when we controlled for selection accuracy in the two awareness tests (intercept of the regression with two predictors; $t(41) = 2.93$, $P < 0.01$, $r = 0.42$). In a final step, we excluded those participants from the analysis of the data from the main experiment, who tended to perform above or below chance level in either of the two awareness tests (12 participants exhibited an awareness score with a binomial probability of $P < 20\%$). Classification accuracy in the main experiment remained above chance level (54.12%, 95% CI [50.72, 57.51], $t(33) = 2.468$, $P = 0.019$, $r = 0.39$) with these 12 participants removed. We, therefore, conclude that there was no awareness of encoding stimuli in the main experiment and that long-term effects derived from unconscious processing alone.

Experiment 2

In experiment 2, we tested for long-term effects using a subliminal vocabulary acquisition task. We hypothesized that new vocabulary would be encoded subliminally influencing delayed lexical–semantic decisions on the same foreign words when they were presented visibly. At test, participants were instructed to decide whether or not a given foreign word and a German translation word fit together (match/mismatch decision). On average, 52.7% (95% CI [50.1, 55.2]) (Fig. 1b) of synonyms were classified accurately, which exceeded chance level (two-tailed t-test: $t(33) = 2.128$; $P = 0.041$; $r = 0.35$). Hence, the meaning of subliminal German words was decoded, linked to foreign words, and stored to influence lexical–semantic decisions 20 min following subliminal encoding.

An interview administered following the main experiment assessed the subjective awareness of the masked stimuli. Participants' responses indicated that none had consciously perceived subliminal words or letters. An objective awareness was used to corroborate the subjective reports. When asked whether a consciously displayed German word represents a synonym to a just subliminally flashed German word, participants decided correctly in 51.3% of cases (95% CI [48.9, 53.8]). This performance did not significantly exceed chance level of 50% ($t(33) = 1.121$, two-tailed $P = 0.27$; $r = 0.19$). To validate whether performance was truly at chance level, we again calculated the Bayes factor for the t-test as suggested by Dienes (2008, 2014). Assuming that awareness for subliminal words should yield a recognition accuracy comparable to performance in the decision task (2.7% above chance level), we chose a half-normal prior distribution with a mode of 0 and a standard deviation of 2.7% to estimate the BF (Dienes, 2014). The resulting factor for the awareness test (mean accuracy = 1.3% above chance level, SE = 1.16%) was 1.14, which suggests that the test was not sensitive enough to reject stimulus awareness. Whether participants were truly unaware of the subliminal words thus remains elusive. However, further analyses suggested that subliminal long-term influences on decision-making did not benefit from stimulus awareness. First of all, a regression analysis (Greenwald *et al.*, 1995) indicated that accuracy in the awareness test did not predict decision accuracy in the main experiment ($\beta = 0.038$, $t(32) = 0.216$, $P = 0.83$), which was above chance level when selection accuracy on the awareness test was 0 (intercept of regression; $t(31) = 2.052$, $P = 0.045$, $r = 0.34$). Furthermore, even if those two participants, who tended to perform above or below chance level in the awareness test (binomial probability of $P < 20\%$), were excluded from the analysis of the data from the main experiment, classification accuracy remained above chance level (52.6%, 95% CI [50.1, 55.1], $t(31) = 2.142$, $P = 0.040$, $r = 0.36$). Although the Bayes analysis yielded an inconclusive result regarding stimulus awareness in the awareness test, the regression analysis suggests that long-term effects on decision-making derived from unconscious processes.

Discussion

To summarize, subliminal verbal and nonverbal item pairs influenced participants' conscious, deliberate decisions almost half an hour following subliminal stimulation. In experiment 1, subliminal face–occupation pairs influenced conscious decisions on the income of the same individuals after delays of 15 and 25 min. In experiment 2, subliminal presentation of foreign language vocabulary influenced participants' decisions on correct/incorrect word translations after a delay of 20 min. These findings provide unprecedented evidence of a considerable longevity of subliminal effects on intentional behavior such as decision-making.

So far, most investigators who addressed the longevity of subliminal priming reported that subliminal effects on behavior would fade within 1 s (e.g. Greenwald *et al.*, 1996), which suggests that subliminal messages leave no long-term memory traces and therefore cannot influence delayed decisions. The few studies which reported longer lasting effects used familiar stimuli that were repeatedly presented to participants who were informed about the presence or purpose of subliminal events (e.g. Chong *et al.*, 2014; Levy *et al.*, 2014). These studies suggest that subliminal information may be stored for long term if it is familiar, if many subliminal exposures are provided for a slow, incremental encoding process, and if subjects explicitly intent to process the subliminal information. Whether novel subliminal information can be integrated and stored following a single exposure to naïve subjects remains unclear. Even less clear is whether a subliminal one-time processing has sufficient strength to influence delayed decision-making. We found that participants, who were unaware of the presence and purpose of subliminal information, successfully processed subliminal face–word and nonword–word pairs and formed lasting unconscious semantic relational memories based on only one or two subliminal encoding episodes (each comprising 12 adjacent subliminal stimulus repetitions).

We speculate that the reported rapid encoding and long-term retention of subliminal information owes to the type of stimuli and the memory system these stimuli called upon. As mentioned above, conclusions regarding the longevity of subliminal priming rested on the use of familiar single-item stimuli such as words (e.g. Forster *et al.*, 1990; Ferrand, 1996; Greenwald *et al.*, 1996). It is known that the processing of single items engages neocortex (Henke et al., 1997; Duss *et al.*, 2014), which forms long-term memory traces rather slowly over many learning trials (McClelland *et al.*, 1995). This might explain why subliminal influences were found to be short-lived or to build up slowly. Here, we used multi-item displays that contained both novel (unfamiliar faces or foreign words) and familiar (occupation words or German translation words) pieces of information. Relational encoding of multiple stimuli engages hippocampus (Henke et al., 1997; Duss *et al.*, 2014), which learns rapidly and stores relations for long term due to its exceptional plasticity (McClelland *et al.*, 1995). Subliminal relational encoding and

retrieval have been associated reliably with hippocampal activity changes (Henke *et al.*, 2003; Reber *et al.*, 2012; Züst *et al.*, 2015). Importantly, hippocampal damage abolished both supraliminal (conscious) and subliminal (unconscious) relational binding but left subliminal single-item priming intact (Duss *et al.*, 2014). As encoding-test intervals spanned a few minutes or less in these previous neuroimaging experiments, they were uninformative regarding longer term effects of subliminal stimuli on behavior. Using similar stimuli and the same masking technique, we now demonstrate subliminal effects on decisions delayed by 15–25 min. Because subliminal influences did not noticeably decay from the delay of 15–25 min in experiment 1, we speculate that subliminally planted information might affect decision-making even at longer intervals.

The long-lasting influence of subliminal stimulus pairs evinces nonconscious relational learning, but the experimental paradigms employed in this study do not pin down the exact nature of the unconsciously formed memories. Although we assume that subliminal stimulus pairs yield semantically precise unconscious relational memories ("person X is a manager", "*gumpel* means *dog*") that are later reactivated to support decision-making, our experimental setup cannot rule out the possibility that participants had formed associations between faces/foreign words and broad semantic or affective categories (e.g. "person X as a manager must be wealthy", "I despise *gumpel* because I fear dogs"). Such fuzzy semantic/affective associations could suffice to guide subsequent decisions ("X has a high income because he is wealthy", "*hound* is a valid translation of *gumpel* because I despise both"). But we would like to point out that the results of earlier investigations on subliminal encoding and long-term memory formation demonstrated unequivocally that subliminal words are understood with high semantic precision. In Duss *et al.* (2011), subliminal presentations of face–occupation pairs influenced participants' subsequent conscious classifications of the same faces when various semantic dimensions were offered, namely regularity of income, length of education, and creativity of work. Faces encoded with an artistic instead of an academic occupation (e.g. "actor" vs. "lawyer") were later classified as generating an irregular income, coming from a shorter school education, and performing creative work. These distinct influences of subliminal information on diverse semantic classifications suggest a precise rather than diffuse lexical–semantic word analysis. Further evidence for precise subliminal encoding is provided by our studies on unconscious relational inference (Reber and Henke, 2012; Reber *et al.*, 2012; Henke *et al.*, 2013). In these studies, overlapping subliminal word pairs such as "winter-red" and "red-computer" (A–B, B–C) were presented apart in time and were nevertheless integrated semantically to influence delayed judgments regarding the semantic relatedness of A and C, like "winter-computer". The successful relational integration in this subliminal paradigm cannot be explained by affective or fuzzy semantic word priming.

Doubts have been raised recently as to whether experimenters had adequately assessed stimulus awareness and correctly estimated influences of subliminal stimuli on behavior (Newell and Shanks, 2014; Hesselmann and Moors, 2015). To avert such suspicion, we assessed stimulus awareness following the main experiments using objective awareness tests that had the same statistical power as our decision tasks. The objective awareness tests confirmed that the subliminal stimulation paradigm rendered stimuli largely (experiment 2) or completely (experiment 1) imperceptible to the conscious mind, and that the observed long-term effects of subliminal stimulation were independent of stimulus awareness. Because we did not assess awareness of each subliminal stimulus immediately following the respective encoding episode in the main experiments, we cannot rule out the possibility that participants were briefly aware of some of the subliminal images. However, none of the participants reported to have noticed the presence of hidden or masked information during the main experiments or during the objective awareness tests. Hence, all available data suggest that the reported long-term influences of subliminal stimuli were independent of consciousness.

The finding that subliminally processed information is rapidly integrated and stored to guide delayed decisions challenges prevailing views of the cognitive function of consciousness. Consciousness is usually considered a precondition for successful information integration (Tononi, 2004; Mudrik *et al.*, 2014), relational learning (Shanks, 2010), and decision-making (Bettman *et al.*, 1998; Simonson, 2005; Newell and Shanks, 2014). However, evidence is accumulating that these notions of consciousness need revision (Dijksterhuis and Nordgren, 2006; Nordgren, 2006; Reder et al., 2009; Henke, 2010; Dew and Cabeza, 2011; Olsen *et al.*, 2012; Hannula and Greene, 2012; van Gaal *et al.*, 2012; Hassin, 2013). Indeed, unconscious integration of different semantic concepts and of temporally or spatially distributed percepts was reported not only for stimuli that were rendered subliminal using visual masking but also for stimuli made invisible using continuous flash suppression (Mudrik *et al.*, 2011; Sklar *et al.*, 2012; Vlassova *et al.*, 2014; Bergström and Eriksson, 2015; Karpinski *et al.*, 2016) or visual crowding (Atas *et al.*, 2013). Even during the unconsciousness of deep sleep, words, sounds, and odors were found to be integrated (Ruby et al., 2008; Daltrozzo, *et al.*, 2012) and stored in long-term memory (Arzi *et al.*, 2012, 2014; Ruch *et al.*, 2014) to modulate behavior following waking. More evidence for the feasibility of unconscious relational integration is provided by social psychology: decisions, which require the consideration, weighing and integration of large amounts of (supraliminally provided) information, were better following unconscious deliberation than conscious reasoning (e.g. Dijksterhuis *et al.*, 2006; Mealor and Dienes, 2012; Abadie *et al.*, 2013). This 'deliberation without attention' effect suggests that our conscious decisions are vitally influenced by nonconscious processes (but see e.g. Newell and Shanks, 2014; Nieuwenstein *et al.*, 2015; and Vadillo *et al.*, 2015 for critical reviews).

In sum, our findings add to a growing body of evidence suggesting that subliminal messages can be used to change our thoughts, attitudes, emotions, and actions (van Gaal *et al.*, 2012; Hassin, 2013). Subliminal stimulation was shown to influence current moods (Monahan *et al.*, 2000), political attitudes (Hassin *et al.*, 2007; Weinberger and Westen, 2008), intentions (Hassin *et al.*, 2007), choices and decisions (Bermeitinger *et al.*, 2009), and cognitive strategies (Lau and Passingham, 2007; Reuss *et al.*, 2011). However, little is known about the longevity of these subliminal influences because these studies were focused mainly on immediate effects of subliminal stimulation. Here, we demonstrate that a few exposures to novel subliminal information is sufficient to influence delayed decision-making. The surprising impact of subliminal messages on rational, intentional, conscious behavior lends subliminal protocols to practical applications, of which advertising is just one example.

Supplementary data

Supplementary data is available at Neuroscience of Consciousness Journal online.

Acknowledgments

This work was supported by Swiss National Science Foundation Grants K-13K1-119953 to K.H. and P0BEP1_148941-1 to M.A.Z.
Behavioral data are available on request.

References

Aarts H, Custers R, Marien H. Preparing and motivating behavior outside of awareness. *Science* 2008;**319**:1639. http://doi.org/10.1126/science.1150432.

Abadie M, Waroquier L, Terrier P. Gist memory in the unconscious-thought effect. *Psychol Sci* 2013;**24**:1253–9. http://doi.org/10.1177/0956797612470958.

Addante RJ. A critical role of the human hippocampus in an electrophysiological measure of implicit memory. *NeuroImage* 2015;**109**:515–28. http://doi.org/10.1016/j.neuroimage.2014.12.069.

Arzi A, Holtzman Y, Samnon P, *et al*. Olfactory aversive conditioning during sleep reduces cigarette-smoking behavior. *J Neurosci* 2014;**34**:15382–93. http://doi.org/10.1523/JNEUROSCI.2291-14.2014.

Arzi A, Shedlesky L, Ben-Shaul M, *et al*. Humans can learn new information during sleep. *Nat Neurosci* 2012;**15**:1460–5. http://doi.org/10.1038/nn.3193

Atas A, Faivre N, Timmermans B, *et al*. Nonconscious learning from crowded sequences. *Psychol Sci* 2013. http://doi.org/10.1177/0956797613499591.

Bergström F, Eriksson J. The conjunction of non-consciously perceived object identity and spatial position can be retained during a visual short-term memory task. *Conscious Res* 2015;1470. http://doi.org/10.3389/fpsyg.2015.01470

Bermeitinger C, Goelz R, Johr N, *et al*. The hidden persuaders break into the tired brain. *J Exp Soc Psychol* 2009;**45**:320–6. http://doi.org/10.1016/j.jesp.2008.10.001

Bettman JR, Luce MF, Payne JW. Constructive consumer choice processes. *J Cons Res* 1998;**25**:187–217. http://doi.org/10.1086/209535

Capa RL, Cleeremans A, Bustin GM, *et al*. Long-lasting effect of subliminal processes on cardiovascular responses and performance. *Int J Psychophysiol* 2011;**81**:22–30. http://doi.org/10.1016/j.ijpsycho.2011.04.001

Chen JCW, Li W, Lui M, *et al*. Left-frontal brain potentials index conceptual implicit memory for words initially viewed subliminally. *Brain Res* 2009;**1285**:135–47. http://doi.org/10.1016/j.brainres.2009.05.085

Chong TTJ, Husain M, Rosenthal CR. Recognizing the unconscious. *Curr Biol* 2014;**24**:R1033–5. http://doi.org/10.1016/j.cub.2014.09.035

Chun MM, Phelps EA. Memory deficits for implicit contextual information in amnesic subjects with hippocampal damage. *Nat Neurosci* 1999;**2**:844–7. http://doi.org/10.1038/12222

Daltrozzo J, Claude L, Tillmann B, *et al*. Working memory is partially preserved during sleep. *PLoS ONE* 2012;**7**:e50997. http://doi.org/10.1371/journal.pone.0050997

Dew ITZ, Cabeza R. The porous boundaries between explicit and implicit memory: behavioral and neural evidence. *Ann NY Acad Sci* 2011;**1224**:174–90. http://doi.org/10.1111/j.1749-6632.2010.05946.x

Dienes Z. *Understanding Psychology as a Science: An Introduction to Scientific and Statistical Inference*. New York: Palgrave Macmillan, 2008.

Dienes Z. Using Bayes to get the most out of non-significant results. *Quant Psychol Meas* 2014;**5**:781. http://doi.org/10.3389/fpsyg.2014.00781

Dijksterhuis A, Bos MW, Nordgren LF, *et al*. On making the right choice: the deliberation-without-attention effect. *Science* 2006;**311**:1005–7. http://doi.org/10.1126/science.1121629.

Dijksterhuis A, Nordgren LF. A theory of unconscious thought. *Perspect Psychol Sci* 2006;**1**:95–109. http://doi.org/10.1111/j.1745-6916.2006.00007.x.

Duss SB, Oggier S, Reber TP, *et al*. Formation of semantic associations between subliminally presented face-word pairs. *Conscious Cogn* 2011;**20**:928–35. http://doi.org/10.1016/j.concog.2011.03.018.

Duss SB, Reber TP, Hänggi J, *et al*. Unconscious relational encoding depends on hippocampus. *Brain* 2014;**137**:3355–70. http://doi.org/10.1093/brain/awu270.

Farooqui AA, Manly T. Anticipatory control through associative learning of subliminal relations: invisible may be better than visible. *Psychol Sci* 2015;**26**:325–34. http://doi.org/10.1177/0956797614564191.

Ferrand L. The masked repetition priming effect dissipates when increasing the inter-stimulus interval: evidence from word naming. *Acta Psychologica* 1996;**91**:15–25. http://doi.org/10.1016/0001-6918(95)00010-0.

Forster K, Booker J, Schacter DL, *et al*. Masked repetition priming: lexical activation or novel memory trace? *Bull Psychon Soc* 1990;**28**:341–5. http://doi.org/10.3758/BF03334039.

Gaillard R, Cohen L, Adam C, *et al*. Subliminal words durably affect neuronal activity. *NeuroReport* 2007;**18**:1527–31. http://doi.org/10.1097/WNR.0b013e3282f0b6cd.

García-Orza J, Damas-López J, Matas A, *et al*. "2 x 3" primes naming "6": evidence from masked priming. *Atten Percept Psychophys* 2009;**71**:471–80. http://doi.org/10.3758/APP.71.3.471

Greene AJ, Gross WL, Elsinger CL, *et al*. An fMRI analysis of the human hippocampus: inference, context, and task awareness. *J Cogn Neurosci* 2006;**18**:1156–73. http://doi.org/10.1162/jocn.2006.18.7.1156

Greene AJ, Gross WL, Elsinger CL, *et al*. Hippocampal differentiation without recognition: an fMRI analysis of the contextual cueing task. *Learn Mem* 2007;**14**:548–53. http://doi.org/10.1101/lm.609807.

Greenwald AG, Draine SC, Abrams RL. Three cognitive markers of unconscious semantic activation. *Science* 1996;**273**:1699–702. http://doi.org/10.1126/science.273.5282.1699

Greenwald AG, Klinger MR, Schuh ES. Activation by marginally perceptible ("subliminal") stimuli: dissociation of unconscious from conscious cognition. *J Exp Psychol-Gen* 1995;**124**:22–42.

Hannula DE, Greene AJ. The hippocampus reevaluated in unconscious learning and memory: at a tipping point? *Front Hum Neurosci* 2012;**6**. http://doi.org/10.3389/fnhum.2012.00080.

Hannula DE, Ranganath C. The eyes have it: hippocampal activity predicts expression of memory in eye movements. *Neuron* 2009;**63**:592–9. http://doi.org/10.1016/j.neuron.2009.08.025.

Harand C, Bertran F, La Joie R, *et al*. The hippocampus remains activated over the long term for the retrieval of truly episodic memories. *PLoS ONE* 2012;**7**:e43495. http://doi.org/10.1371/journal.pone.0043495.

Hassin RR. Yes it can: on the functional abilities of the human unconscious. *Perspect Psychol Sci* 2013;**8**:195–207. http://doi.org/10.1177/1745691612460684.

Hassin RR, Ferguson MJ, Shidlovski D, *et al*. Subliminal exposure to national flags affects political thought and behavior. *Proc Natl Acad Sci USA* 2007;**104**:19757–61. http://doi.org/10.1073/pnas.0704679104.

Henke K. A model for memory systems based on processing modes rather than consciousness. *Nat Rev Neurosci* 2010;**11**:523–32. http://doi.org/10.1038/nrn2850.

Henke K, Buck A, Weber B, *et al*. Human hippocampus establishes associations in memory. *Hippocampus* 1997;**7**:249–56. http://doi.org/10.1002/(SICI)1098-1063(1997)7:3<249::AID-HIPO1>3.0.CO;2-G.

Henke K, Mondadori CRA, Treyer V, *et al*. Nonconscious formation and reactivation of semantic associations by way of the medial temporal lobe. *Neuropsychologia* 2003;**41**:863–76. http://doi.org/10.1016/S0028-3932(03)00035-6.

Henke K, Reber TP, Duss SB. Integrating events across levels of consciousness. *Front Behav Neurosci* 2013;**7**:68. http://doi.org/10.3389/fnbeh.2013.00068.

Hesselmann G, Moors P. Definitely maybe: can unconscious processes perform the same functions as conscious processes? *Conscious Res* 2015;**584**. http://doi.org/10.3389/fpsyg.2015.00584.

Holdstock JS, Mayes AR, Isaac CL, *et al*. Differential involvement of the hippocampus and temporal lobe cortices in rapid and slow learning of new semantic information. *Neuropsychologia* 2002;**40**:748–68. http://doi.org/10.1016/S0028-3932(01)00192-0.

Karpinski A, Yale M, Briggs JC. Unconscious arithmetic processing: a direct replication. *Eur J Soc Psychol* 2016; n/a-n/a. http://doi.org/10.1002/ejsp.2175.

Karremans JC, Stroebe W, Claus J. Beyond Vicary's fantasies: the impact of subliminal priming and brand choice. *J Exp Soc Psychol* 2006;**42**:792–8. http://doi.org/10.1016/j.jesp.2005.12.002.

Kawakami N, Yoshida F. Perceiving a story outside of conscious awareness: when we infer narrative attributes from subliminal sequential stimuli. *Conscious Cogn* 2015;**33**:53–66. http://doi.org/10.1016/j.concog.2014.12.001.

Kiesel A, Wagener A, Kunde W, *et al*. Unconscious manipulation of free choice in humans. *Conscious Cogn* 2006;**15**:397–408. http://doi.org/10.1016/j.concog.2005.10.002.

Klapp ST, Haas BW. Nonconscious influence of masked stimuli on response selection is limited to concrete stimulus-response associations. *J Exp Psychol-Hum Percept Perform* 2005;**31**:193–209. http://doi.org/10.1037/0096-1523.31.1.193.

Lau HC, Passingham RE. Unconscious activation of the cognitive control system in the human prefrontal cortex. *J Neurosci* 2007;**27**:5805–11. http://doi.org/10.1523/JNEUROSCI.4335-06.2007.

Levy BR, Pilver C, Chung PH, *et al*. Subliminal strengthening: improving older individuals' physical function over time with an implicit-age-stereotype intervention. *Psychol Sci* 2014;**2525**:2127–35. http://doi.org/10.1177/0956797614551970.

Lowery BS, Eisenberger NI, Hardin CD, *et al*. Long-term effects of subliminal priming on academic performance. *BASP* 2007;**29**:151–7. http://doi.org/10.1080/01973530701331718.

McClelland JL, McNaughton BL, O'reilly RC. Why there are complementary learning systems in the hippocampus and neocortex: insights from the successes and failures of connectionist models of learning and memory. *Psychol Rev* 1995;**102**:419–57.

Mealor AD, Dienes Z. Conscious and unconscious thought in artificial grammar learning. *Conscious Cogn* 2012;**21**:865–74. http://doi.org/10.1016/j.concog.2012.03.001.

Miller J. Measurement error in subliminal perception experiments: simulation analyses of two regression methods. *J Exp Psychol-Hum Percept Perform* 2000;**26**:1461–77.

Monahan JL, Murphy ST, Zajonc RB. Subliminal mere exposure: specific, general, and diffuse effects. *Psychol Sci* 2000;**11**:462–6. http://doi.org/10.1111/1467-9280.00289.

Moscovitch M. Recovered consciousness: a hypothesis concerning modularity and episodic memory. *J Clin Exp Neuropsychol* 1995;**17**:276–90. http://doi.org/10.1080/01688639508405123.

Mudrik L, Breska A, Lamy D, *et al*. Integration without awareness: expanding the limits of unconscious processing. *Psychol Sci* 2011;**22**:764–70. http://doi.org/10.1177/0956797611408736.

Mudrik L, Faivre N, Koch C. Information integration without awareness. *Trends Cogn Sci* 2014;**18**:488–6. http://doi.org/10.1016/j.tics.2014.04.009.

Mudrik L, Koch C. Differential processing of invisible congruent and incongruent scenes: a case for unconscious integration. *J Vis* 2013;**13**:24. http://doi.org/10.1167/13.13.24.

Negash S, Kliot D, Howard DV, *et al*. Relationship of contextual cueing and hippocampal volume in amnestic mild cognitive impairment patients and cognitively normal older adults. *J Int Neuropsychol Soc* 2015;**21**:285–96. http://doi.org/10.1017/S1355617715000223.

Newell BR, Shanks DR. Unconscious influences on decision making: a critical review. *Behav Brain Sci* 2014;1–19. http://doi.org/10.1017/S0140525X12003214.

Nieuwenstein MR, Wierenga T, Morey RD, *et al*. On making the right choice: a meta-analysis and large-scale replication attempt of the unconscious thought advantage. *Judgm Decis Mak* 2015;**10**:1–17.

Ocampo B. Unconscious manipulation of free choice by novel primes. *Conscious Cogn* 2015;**34**:4–9. http://doi.org/10.1016/j.concog.2015.03.007.

Olsen RK, Moses SN, Riggs L, *et al*. The hippocampus supports multiple cognitive processes through relational binding and comparison. *Front Hum Neurosci* 2012;**6**:146. http://doi.org/10.3389/fnhum.2012.00146.

Parkinson J, Haggard P. Subliminal priming of intentional inhibition. *Cognition* 2014;**130**:255–65. http://doi.org/10.1016/j.cognition.2013.11.005.

Reber TP, DoLam A, Elger CE, *et al*. Intracranial EEG correlates of implicit relational inference within the hippocampus. *Hippocampus* 2016;**26**:54–66. http://doi.org/10.1002/hipo.22490.

Reber TP, Henke K. Integrating unseen events over time. *Conscious Cogn* 2012;**21**:953–60. http://doi.org/10.1016/j.concog.2012.02.013

Reber TP, Luechinger R, Boesiger P, *et al*. Unconscious relational inference recruits the hippocampus. *J Neurosci* 2012;**32**:6138–48. http://doi.org/10.1523/JNEUROSCI.5639-11.2012.

Reder LM, Park H, Kieffaber PD. Memory systems do not divide on consciousness: Reinterpreting memory in terms of activation and binding. *Psychol Bull* 2009;**135**:23–49. http://doi.org/10.1037/a0013974.

Reuss H, Kiesel A, Kunde W, *et al*. Unconscious activation of task sets. *Conscious Cogn* 2011;**20**:556–67. http://doi.org/10.1016/j.concog.2011.02.014.

Ruby P, Caclin A, Boulet S, *et al*. Odd sound processing in the sleeping brain. *J Cognitive Neurosci* 2008;**20**:296–311. http://doi.org/10.1162/jocn.2008.20023.

Ruch S, Koenig T, Mathis J, *et al*. Word encoding during sleep is suggested by correlations between word-evoked up-states and post-sleep semantic priming. *Front Psychol* 2014;**5**:1319. http://doi.org/10.3389/fpsyg.2014.01319.

Schlaghecken F, Eimer M. Masked prime stimuli can bias "free" choices between response alternatives. *Psychon Bull Rev* 2004;**11**:463–8. http://doi.org/10.3758/BF03196596.

Shanks DR. Learning: from association to cognition. *Annu Rev Psychol* 2010;**61**:273–301. http://doi.org/10.1146/annurev.psych.093008.100519.

Simonson I. In defense of consciousness: the role of conscious and unconscious inputs in consumer choice. *J Cons Psychol* 2005;**15**:211–17. http://doi.org/10.1207/s15327663jcp1503_5.

Sklar AY, Levy N, Goldstein A, *et al*. Reading and doing arithmetic nonconsciously. *Proc Natl Acad Sci USA* 2012. http://doi.org/10.1073/pnas.1211645109.

Squire LR, Zola SM. Structure and function of declarative and nondeclarative memory systems. *Proc Natl Acad Sci USA* 1996;**93**:13515–22.

Strahan EJ, Spencer SJ, Zanna MP. Subliminal priming and persuasion: striking while the iron is hot. *J Exp Soc Psychol* 2002;**38**:556–68. http://doi.org/10.1016/S0022-1031(02)00502-4

Tononi G. An information integration theory of consciousness. *BMC Neurosci* 2004;**5**:42. http://doi.org/10.1186/1471-2202-5-42.

Tulving E. Episodic memory: from mind to brain. *Annu Rev Psychol* 2002;**53**:1–25. http://doi.org/Article

Vadillo MA, Kostopoulou O, Shanks DR. A critical review and meta-analysis of the unconscious thought effect in medical decision making. *Conscious Res* 2015;636. http://doi.org/10.3389/fpsyg.2015.00636.

Van den Bussche E, Van den Noortgate W, Reynvoet B. Mechanisms of masked priming: a meta-analysis. *Psychol Bull* 2009;**135**:452–77. http://doi.org/10.1037/a0015329.

van Gaal S, De Lange FP, Cohen MX. The role of consciousness in cognitive control and decision making. *Front Hum Neurosci* 2012;**6**:121. http://doi.org/10.3389/fnhum.2012.00121.

Van Opstal F, de Lange FP, Dehaene S. Rapid parallel semantic processing of numbers without awareness. *Cognition* 2011;**120**:136–47. http://doi.org/10.1016/j.cognition.2011.03.005.

Verwijmeren T, Karremans JC, Bernritter SF, *et al*. Warning: You are being primed! The effect of a warning on the impact of subliminal ads. *J Exp Soc Psychol* 2013;**49**:1124–9. http://doi.org/10.1016/j.jesp.2013.06.010.

Verwijmeren T, Karremans JC, Stroebe W, *et al*. The workings and limits of subliminal advertising: the role of habits. *J Cons Psychol* 2011;**21**:206–13. http://doi.org/10.1016/j.jcps.2010.11.004.

Vlassova A, Donkin C, Pearson J. Unconscious information changes decision accuracy but not confidence. *Proc Natl Acad Sci USA* 2014;**111**:16214–8. http://doi.org/10.1073/pnas.1403619111.

Weinberger J, Westen D. RATS, we should have used Clinton: subliminal priming in political campaigns. *Polit Psychol* 2008;**29**:631–51. http://doi.org/10.1111/j.1467-9221.2008.00658.x.

Züst MA, Colella P, Reber TP, *et al*. Hippocampus is place of interaction between unconscious and conscious memories. *PLoS ONE* 2015;**10**:e0122459. http://doi.org/10.1371/journal.pone.0122459.